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ON CALCULATING HOUSE ENERGY CONSUMPTION SIMPLY

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The traditional degree-day method for determining the energy consumption of houses is discussed. Based on actual house data, the correction factor in the formulation, the C-factor, is shown to be house-specific, with an average value of 19.

INTRODUCTION

The basic thermal characterization of a house envelope is the same for heat loss and energy consumption calculations (essentially the sum of component area/resistance times relevant temperature difference). For the heat loss, to size the heating system, a design (ie extreme cold) temperature difference is used, together with the assumption that no other sources of heat are operative. For energy, a heating season integration incorporating internal and solar gains is needed. The traditional degree-day method/1/ is meant to capture the simplicity of the heat loss calculation for an energy determination. This report discusses the empirical correction factor required by this method, and the resulting accuracy of the method.

THE DEGREE-DAY METHOD

The standard formulation, slightly adapted for the electrical heating situation from reference 1, is reproduced below:

$$E = \frac{H_L \cdot D \cdot 24}{\Delta T \cdot k \cdot V} \cdot C_D \qquad (1)$$

where

- E = fuel or energy consumption for the estimate period, kW•h.
- H_L = design heat loss, including infiltration and ventilation, kW.
- D = number of 18°C degree-days for the estimate period.
- ΔT = design temperature difference, °C.
- k = a correction factor that includes the effects of rated full load efficiency, part load performance, oversizing and energy conservation devices.
- V = heating value of fuel, units consistent with H_L and E.
- C_D = empirical correction factor for heating effect versus 18°C days, dimensionless.

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Although empirical, this equation has some basis in physical fact. In an approximate sense, $H_L/\Delta T$ can be thought of as an overall inside-to-outside thermal conductance (UA) for the building. In a similar sense, the D can be thought of as the inside-to-outside temperature difference averaged over the day, so that the product yields the daily heating load. Division by the fuel heating value yields the ideal amount of fuel required for the day. The constant is for unit conversion, ie, 24 h/da. The factors k and C_D are empirical and attempt to account for the various effects noted in their definitions/1/.

With H_L in kW, V = 1. For electrical heating options, k is shown in Table 1 /2/.

Table 1

Electric Heating System Efficiencies

Resistance (unitary or central, forced air or hydronic)	1.0
radiant heating	0.95
all-electric air-source heat pump system	1.8
ground-source heat pump system	2.4
add-on air-source heat pump replacing 60% of back-up fuel	2.2
bivalent heat pump replacing 88% of back-up fuel	1.9

THE CORRECTION FACTOR

The only remaining parameter to discuss is C_D. It is important to note that heat loss analysts in utilities usually combine C_D with the 24 h/da conversion factor to yield the empirical "C-factor". Fifty years ago, the combination of appliance usage and thermal insulation in houses meant that heating began to be required below 18°C. The standard degree-day statistic is based on this fact. Heating from 18°C to the thermostat setting was accomplished with internal and solar gains. The increased insulation levels in housing, the vast increase in household appliances and the increased variation in thermostat settings since that time have resulted in the need for a correcting C-factor. If degree-days were accumulated to a house-specific base temperature (other than 18°C), then the C-factor would equal 24, by definition. Detailed monitoring and analysis of 47 Ontario houses in a dual-fuel field experiment yielded the range of base temperatures reproduced as Figure 1 /4/.

The average base temperature of 14.6°C agrees well with that proposed in reference 3, viz 13.9°C. Note the wide distribution of base temperatures, indicating the large actual variations in thermostat settings, insulation levels, solar utilization and appliance usage. The range to include one standard deviation on either side of the mean runs from 12°C to 17°C.

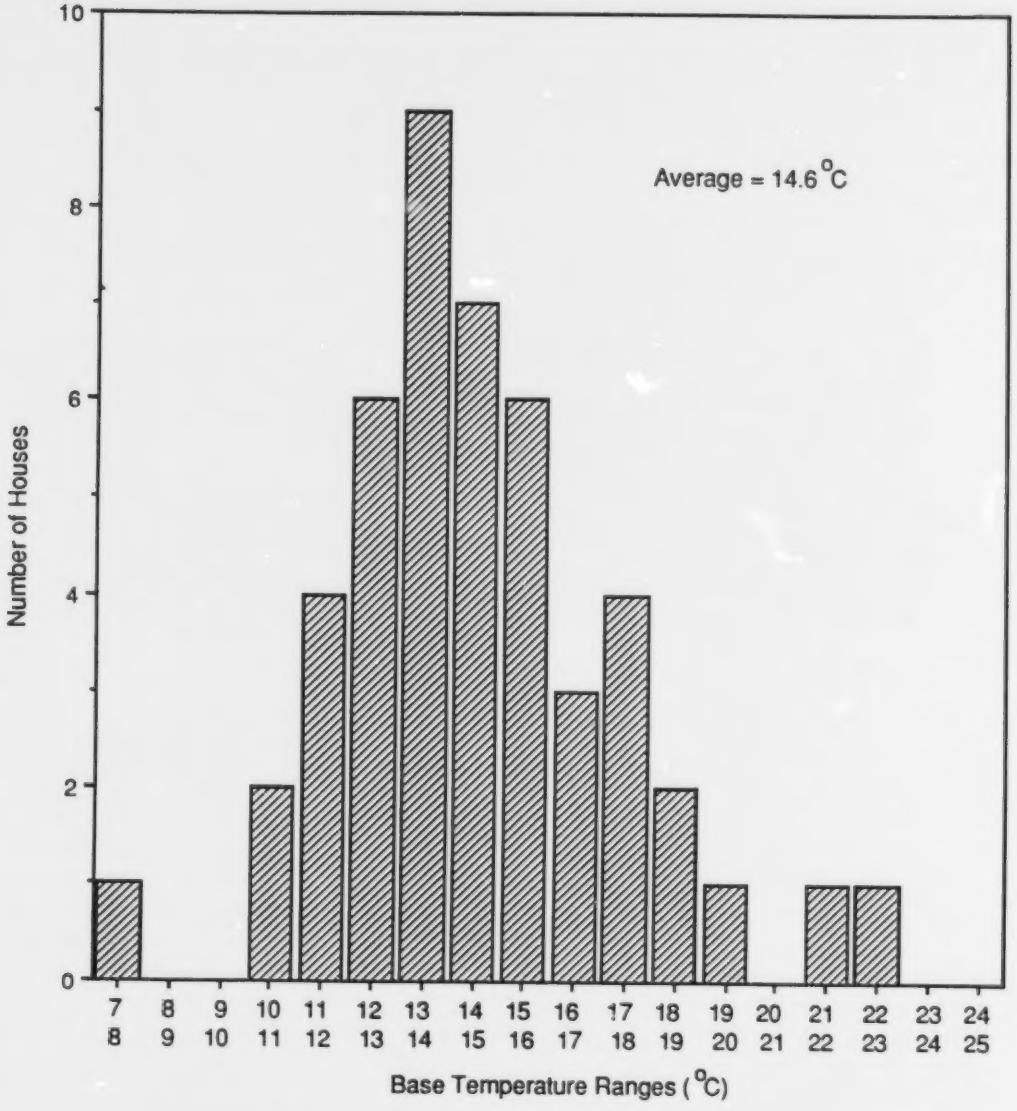

FIGURE 1

EXPERIMENTAL DEGREE DAY BASE TEMPERATURES /4/

THEORETICAL C-FACTORS

The simplicity of the degree-day method is partly lost if variable degree-day base temperatures are introduced. (Such a method is also discussed in reference 1.) Equivalently, C-factors can be determined corresponding to various base temperatures as laid out below, preserving the simple method, but with a firmer theoretical basis than the pure empiricism previously employed.

Equation 2, which is purely definitional, forms the basis for the theory.

$$D_{18} \cdot \text{C-factor} = D_B \cdot 24 \qquad (2)$$

where D_{18} = number of degree-days to base 18°C
C-factor = $24 \cdot C_B$ from equation (1)
D_B = number of degree-days to the variable base temperature (B, °C) appropriate to a specific house
and 24 = conversion from days to hours.

Using long-term weather statistics for Pearson International Airport (Toronto) previously developed in reference 5 to calculate degree-days to various bases, allows calculation of C-factor vs base temperature (B), shown in Table 2. (Another formulation is presented in the Appendix.) It is postulated that other Ontario weather locations would yield quite similar results, ie the weather profile is essentially the same throughout the province. This assertion cannot readily be checked except by detailed calculations on specific houses, or by local experience (for solar effects play a role). The basic inaccuracy of the method, discussed in detail below, allows some location-specific variation before the overall accuracy of the method, as outlined in Table 2, is significantly compromised.

Table 2

C-Factor Versus Degree-Day Base Temperature
(Toronto weather, D_{18} = 4144°C-da)

B (°C)	D_B (°C-da)	C-factor (h/da)	C_D (-)
22	5427	31.4	1.31
20	4792	27.8	1.16
18	4181	24.2	1.01
16	3629	21.0	0.88
14	3118	18.1	0.75
12	2630	15.2	0.63
10	2192	12.7	0.53
8	1802	10.4	0.43

Recalling the range of base temperatures from Figure 1, this table shows the large differences in energy consumption that can result for houses with the same heat loss but differing characteristics. Houses with C-factors one standard deviation from the mean C-factor (= 19.0 by interpolation) use 20% more or less energy. This graphically illustrates the basic shortcoming in using this too simple method. If such errors are acceptable for a rough indication of energy consumption, then the simplicity is a major benefit.

DISCUSSION

More sophisticated methods of calculating energy consumption are available; sufficient accuracy is probably obtained by using month-by-month methods, such as the micro-computer program, HOT-2000/6/. Note that most of the input required by such a method is already needed to calculate a heat loss, although further characterization of solar shading, appliance usage, etc are required.

The indefiniteness of the degree-day method is clarified if the actual base temperature for the house in question is known. This is in general not the case without resorting to a more detailed calculation procedure. For existing houses, analysis of the bills using another micro-computer program, PRISM/7/, gives the best-fit base temperature for that house, and the weather-normalized annual energy consumption (rendering the degree-day calculation redundant). We are thus usefully left with the degree-day method only in cases where the specific base temperature is not available, and we have the resulting range of C-factors to live with.

One other source of error in the degree-day method not explicitly mentioned in the ASHRAE discussion/1/ is that H_L is generally a too-large estimate of the design heat loss, so that the risk of undersizing the heating system is small. It is likely that empirical C-factors are smaller than those proposed above to compensate for this situation. As discussed in reference 8, the amount of such oversizing is difficult to quantify, and is a variable among houses. Measured design heat losses include time constant effects and the actual appliance usage (not zero as assumed in standard heat loss calculations), and so may give a biased indication of the extent of oversizing. No quantitative correction to the C-factor can thus be presented, but only the observation that the effect will tend to lower the appropriate value from that suggested by the theoretical considerations embodied in Table 2. This source of error is not likely to be large with respect to the base temperature (B) variability, but it is systematic. This question can only be resolved through further empirical work.

CONCLUSION

The major correction needed to give accurate energy consumptions for houses from the traditional degree-day method entails estimating the house-specific base temperature (that temperature below which heating is required). This estimation can be transformed into choosing a corresponding C-factor.

RECOMMENDATION

For Ontario houses, it is recommended that an average C-factor of 19 be used. Variations of 20% from that value (ie 15 to 23) are easily possible, and even larger deviations can occur.

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REFERENCES

1. ASHRAE Handbook 1985 Fundamentals, p 28.2.

2. W.R. Jones, "Energy Saving and Conversion Factors", OHRD Report, to be published.

3. L.W. Crow, "Weather Year for Energy Calculations", ASHRAE Journal, June 1984, p 43.

4. R.L. Hicks, F.G. Pellini & C.E. Keyes, "Displacing Oil Using Dual Energy Heating in Canadian Homes", CEA Report 120U281, July 1984, Figure C-7.

5. W.R. Jones, "Heating Season Calculations", memo to file 814.34, 1982 Feb 15.

6. HOT-2000, available from Energy Analysis Software, P O Box 7081, Postal Station J, Ottawa, Ontario K2A 3Z6.

7. PRISM, available from Center for Energy & Environmental Studies, The Engineering Quadrangle, Princeton University, Princeton, New Jersey 08544.

8. W.R. Jones & B.T. Howell, "Comparison of Heating Load Calculation Methods with Measured Data", OHRD Report 85-299-K, 1985 Oct 23.

APPENDIX

Another, simpler, way of expressing the C-factor versus T_B relationship is here developed. It again assumes that the weather characteristic important for degree-day purposes is essentially invariant with respect to location, at least within Ontario. The basic degree-day relationship is between design heat loss and annual energy consumption. This appendix suggests a single proportionately constant between the two, whose only parameter is T_B. Equation 1 is thus rewritten

$$E = K(T_B)\, H_L \,/\, (k \cdot V) \qquad \text{(A1)}$$

where K obviously replaces $D_{18} \cdot 24 \cdot C_D \,/\, \Delta T$ from equation 1. Again using Pearson International Airport data, Table A1 gives K as a function of T_B. One can think of K as the full-load-equivalent heating season length in hours.

Table A1

Energy to Design Heat Loss Proportionality Constant
as a Function of Degree-Day Base Temperature
(Toronto Weather, ΔT_{design} = 40°C)

T_{base} (°C)	K ($\sim E/H_L$) (h/a)
22	3260
20	2880
18	2510
16	2180
14	1870
12	1580
10	1320
8	1080

Again, the average proportionality constant, based on the data in Figure 1, is 1970 (or roughly 2000) h/a (or kWh/a per kW), with a one standard deviation range between 1600 h/a and 2400 h/a.